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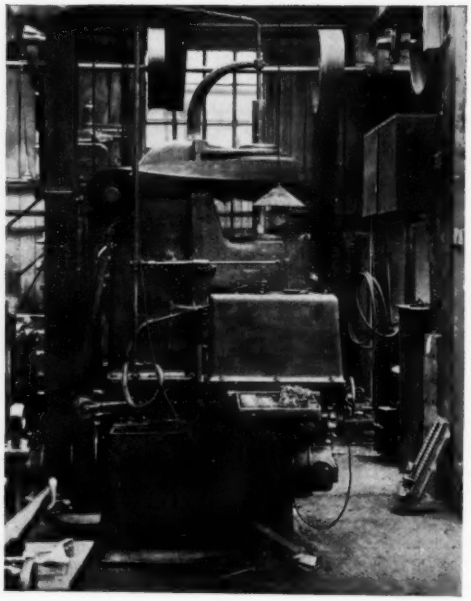

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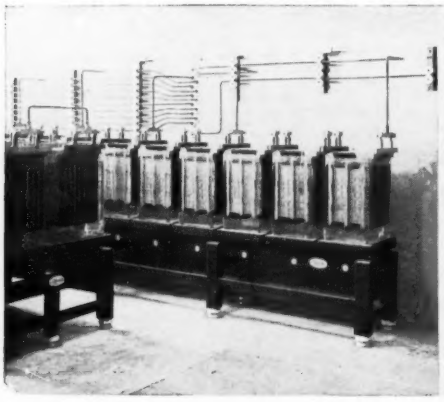

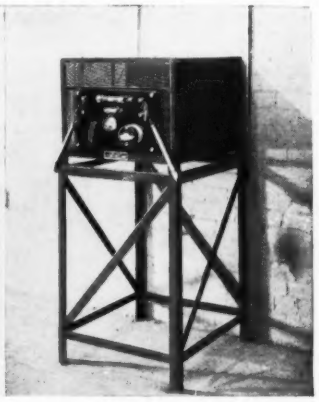

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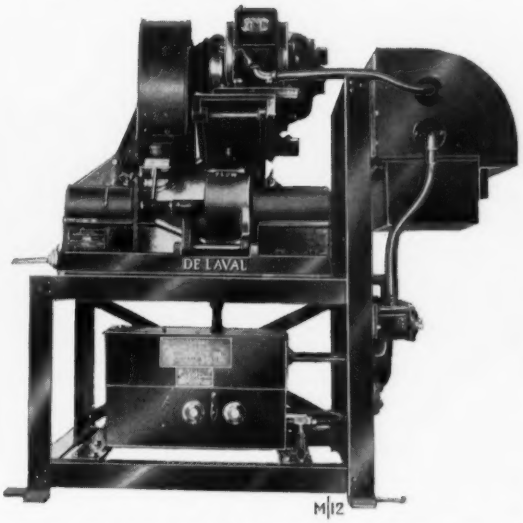

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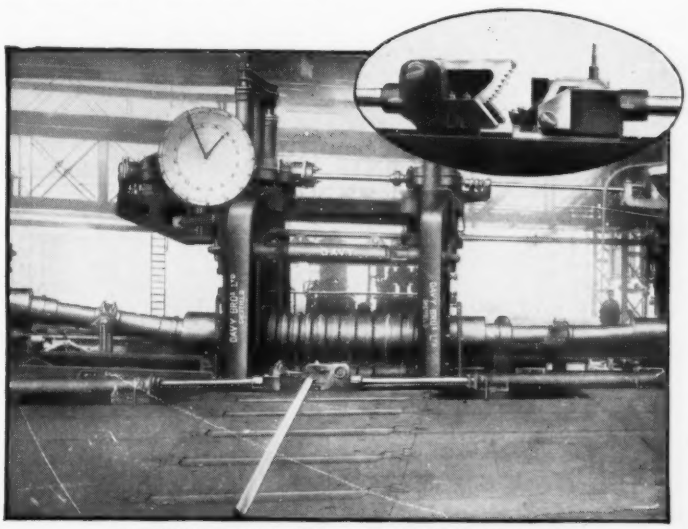

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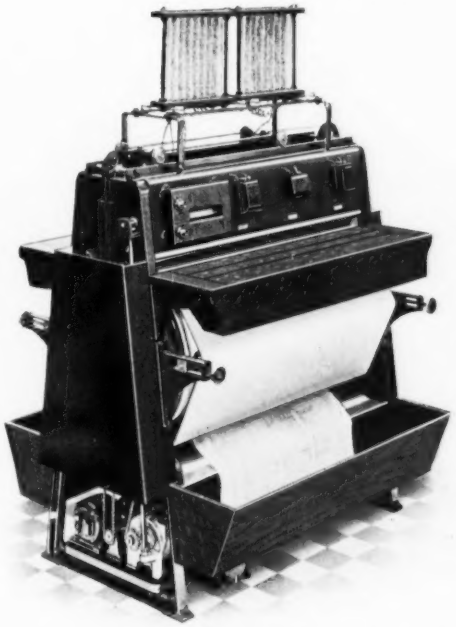

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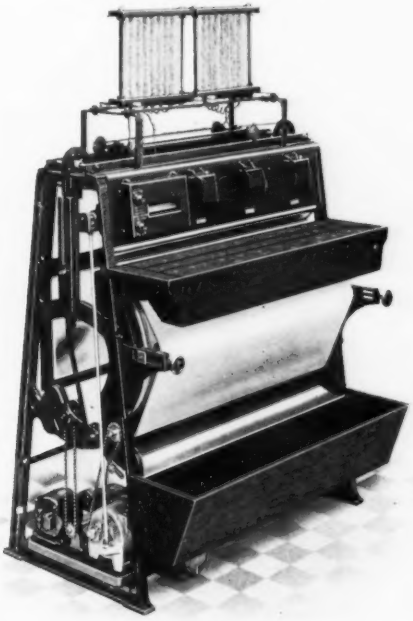

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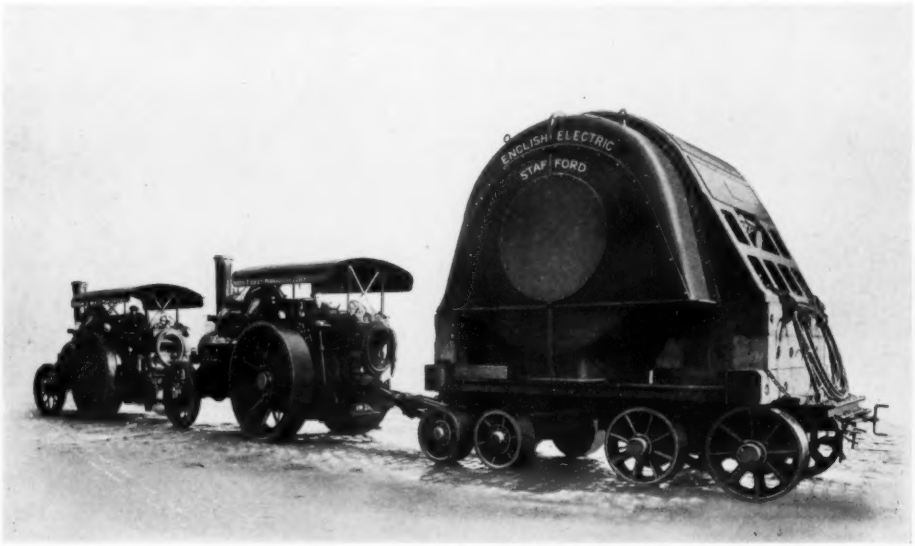

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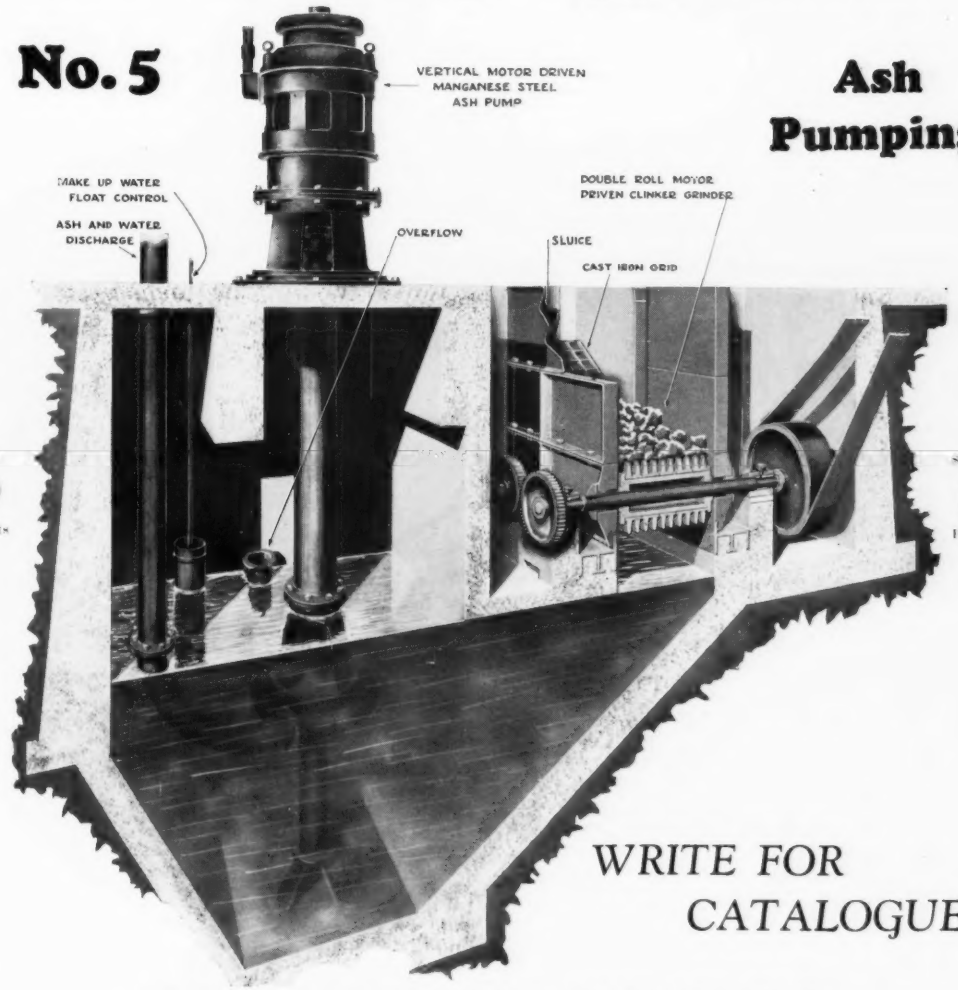

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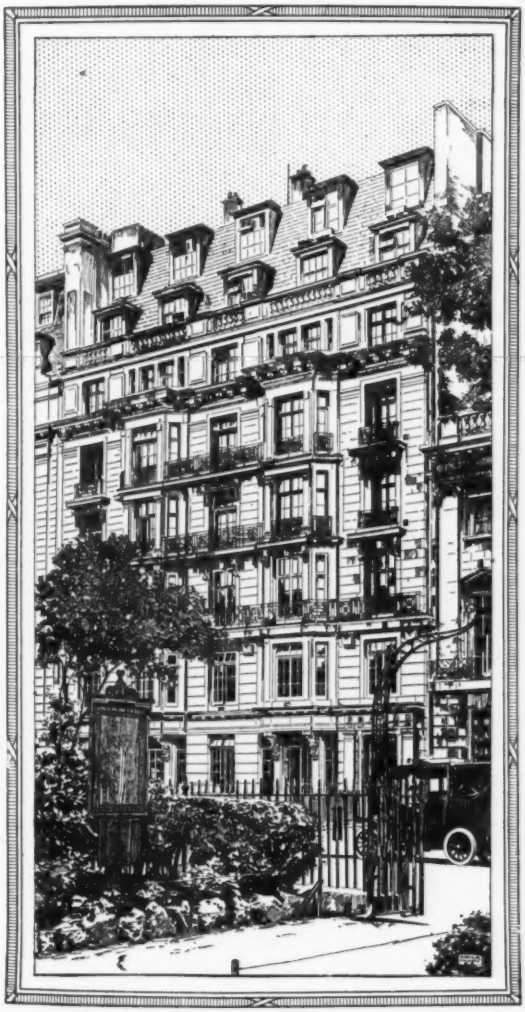

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The Lochaber Hydro-electric Power Station of the North British Aluminium Company, containing five 10,000 H.P. Water Turbines driving D.C. generators having an aggregate output of 100,000 amperes.

The English Electric Journal

Vol. V. No. 4 NOVEMBER 1930 One Shilling.

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All Communications respecting Editorial Contents should be addressed to THE EDITOR, THE ENGLISH ELECTRIC JOURNAL, QUEEN'S HOUSE, KINGSWAY, LONDON, W.C.2.

EDITORIAL.

This issue of the Journal is devoted mainly to a description of some large generating plants which represent the latest developments in their several classes, and present many noteworthy features. The prime movers are of the steam turbine and hydraulic types, and in the latter case both impulse and reaction machines come under review.

The steam turbine set recently installed at West Ham was the largest in this country running at 3,000 r.p.m. The set has an output of 30,000 kW. and, as illustrating the great advance that has been made in heavy engineering during recent years, it may be mentioned that prior to the war the largest unit running at this speed had a capacity of only 3,000 kW. or one-tenth that of the new machine. The steam set comprises turbine, generator, and condenser, while the hydraulic installations described in the following article include both impulse and reaction wheels, large alternators and direct-current generators, and main hydraulic valves; and the Company has the distinction of being the only firm, not only in this country but in the world, with one possible exception, that designs and manufactures in its own shops all these several items. The

advantages of this are obvious; not only is there the most complete collaboration of designers and shop engineers, but the various component parts can readily be brought together for fitting and adjustment in the Works. There is further the great advantage that erection on site is in the hands of a single contracting party.

The hydraulic machines we describe are the largest installed in Great Britain, and they have been designed and manufactured entirely in our Works. Further it may be mentioned that, including the reconstructed machines at Kinlochleven, all the large water turbines operating in Scotland have been manufactured by the Company. Our readers have doubtless seen many references in the Press to the Lochaber scheme of the British Aluminium Company with its great tunnel, 15 miles long, through the massif of Ben Nevis. The completed scheme must for all time be the largest in Great Britain as there is no other catchment area capable of supplying the same amount of power from a single generating station. The turbines work under a head of about 800 ft., and the generators feed direct current straight to the aluminium furnaces. Each commutator deals with a current of 10,000 amperes and, although the machines are in continuous full-load service day and night, commutation is entirely satisfactory, indeed more so than with many machines of only one tenth the output. In this connection it is of interest to note that the direct-current generators at Kinlochleven, manufactured by the Company more than 20 years ago, are to-day as satisfactory in operation as when they were first installed.

In a short article at the end of the Journal reference is made to some electric locomotives for industrial purposes that have recently been manufactured by the Company. Industrial concerns are realising more and more the advantages of these locomotives and the economies that result from their introduction.

New Traction Contracts. Amongst the orders for electric traction material that have been received recently, the following are of special interest.

For the **Buenos Aires Great Southern Railway** the Company is manufacturing 68 motors and control gear for an aggregate of about 10,000 h.p. This material forms the propelling equipment for a number of Diesel-electric trains and locomotives.

Following the successful trial of a special design of tramway track the **Liverpool Corporation** has placed an order for 24 of these units, together with control equipments for 12 cars.

The **Calcutta Tramways Company** has ordered a number of articulated units specially designed to meet the local traffic conditions.

A contract has just been received from the **Leyton Borough Council** for 50 double-deck tramcar bodies of the most modern type, similar in design to the 50 bodies which the Company has recently completed for the London County Council.

The total value of the above-mentioned orders exceeds £160,000.

New Steam Turbine Plant at West Ham & Bradford.

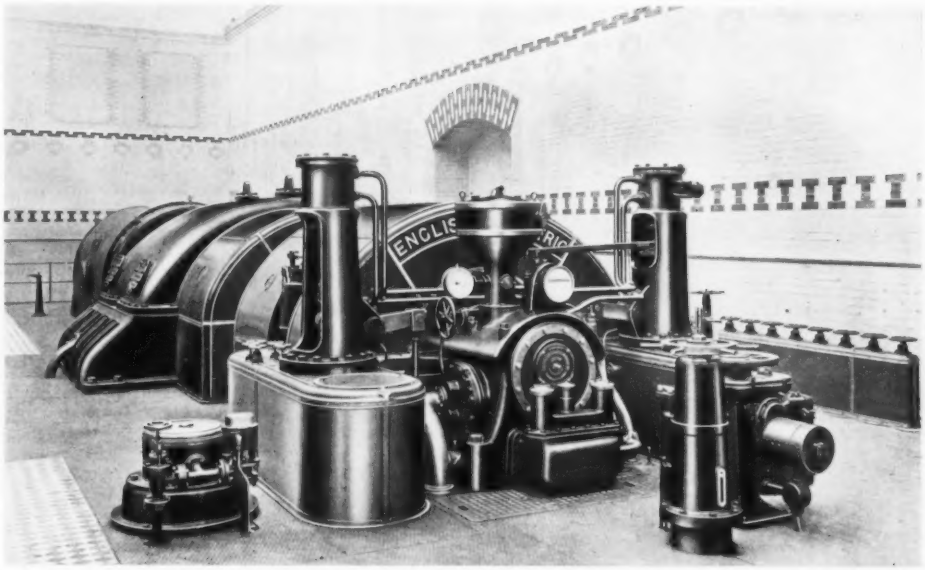


Fig. 1.—Three-cylinder "English Electric" Turbine Driving 30,000 kW., 3,000 r.p.m. Alternator at Bradford.

The West Ham Corporation and the Bradford Corporation have recently increased the capacity of their power stations by the installation of a 30,000-kW. "English Electric" steam turbine, and these units were the largest machines of their type and running at 3,000 r.p.m. to be put into service in Great Britain. The unit at Bradford was formally started up by H.R.H. Princess Mary on September 18th last; the West Ham set, which has been in successful operation for several months, was formally started on November 7th by Mr. Morrison, Minister of Transport.

The turbines are generally of similar design, with such slight modifications as were necessitated by the operating conditions. They are of the multi-cylinder type which the Company has made familiar to power station engineers, and each comprises a high-pressure impulse cylinder and two low-pressure reaction cylinders in one line. The advantages of this design may be summarised as a combination of high steam economy with sound mechanical design and low stresses.

As installed at Bradford the new plant forms part of an important extension to the Valley Road power station, which, when completed, will carry into effect a scheme evolved by Mr. Thomas Roles, M.I.E.E., the chief electrical engineer, for compounding the station. The 1,100 lbs.-per-square-inch boiler and the 2,500-kW. high-pressure turbo-alternator set built by the Company, which will constitute the high-pressure section, will be put into service in the near future. The 30,000 kW. turbine operates with steam at a pressure of 190 lbs. per square inch, and a total temperature of 754°F. and exhausts into a single-shell "English Electric" condenser which maintains a vacuum of 28½ in. Hg (bar. 30 in.); a view of this machine is shown in Fig. 1.

For the purpose of this article a detailed description will be given of the West Ham turbine, which is directly coupled to a two-phase 6,000/7,000-volt alternator also manufactured by the English Electric Company. The steam conditions in this case are 200 lbs. per square inch, and 700°F. total

temperature, and as at Bradford, the condenser is of the Company's latest single-shell design.

Steam enters the high-pressure cylinder by way of a separator, a main stop-valve and twin throttle valves and passes from this cylinder to the first low-pressure cylinder through two overhead pipes, and to the second low-pressure cylinder through similar pipes underneath the turbine floor. From the sectional arrangement in Fig. 3 it will be seen that in the two low-pressure cylinders the steam flows from the outer ends towards the centre where a single exhaust opening communicates with the condenser. It follows that the two rotors are balanced axially in respect of the steam flow.

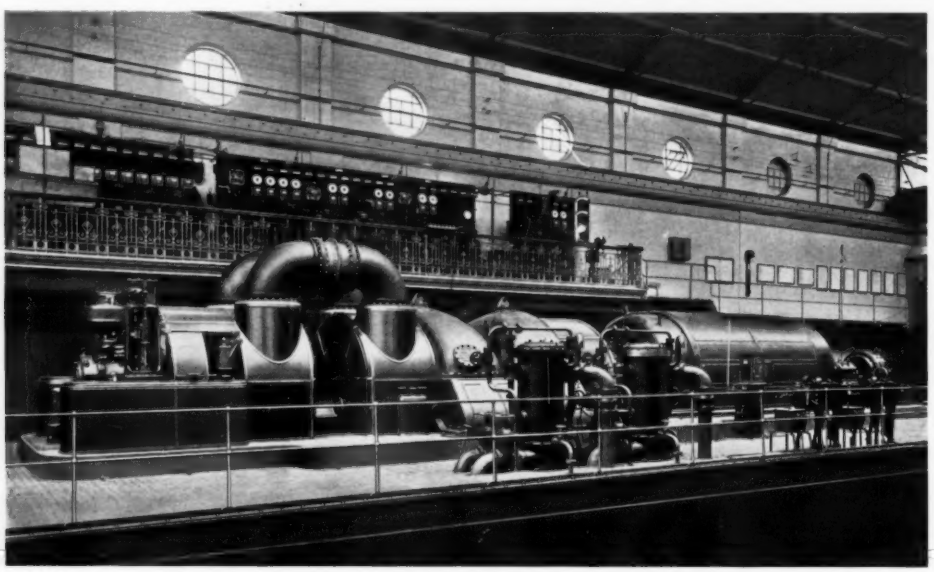


Fig. 2.—30,000-kW., 3,000 r.p.m. Turbo-alternator Set at West Ham.

All the cylinders are bolted together to form one complete unit, but the assembly is anchored rigidly to the foundations only at a point near the centre, thus allowing freedom for expansion in any direction from that point, while alignment is preserved by co-axial keys on which the outer supporting feet can slide.

The high-pressure rotor carries twelve single-row impulse stages, the discs of which are mounted on the shaft by a special form of ring fixing that ensures a high degree of security while permitting expansion. The blades are machined from solid steel bar and formed with self-contained distance pieces, and roots of T section which fit into corresponding grooves in the rotor periphery. Tangs are formed at the outer end of each blade for the attachment of a shrouding strip which is secured by riveting the tangs; the shrouding is not continuous but is fitted in sections in order to permit expansion.

Cast steel is used for all parts of the high-pressure casing that are subjected to steam of high pressure and temperature. The nozzle plate and the following eight diaphragms are of steel of the built-up type, while the last three diaphragms are cast-iron with division plates cast in.

The two low-pressure rotors are separate units running in their own bearings. Each has ten rows of reaction blading mounted on discs which are shrunk on the shaft and finally turned up to give the finish of a solid unit. The discs have been designed with special care directed to securing low stresses at every section. The reaction type blading has serrated root fixing except on the last two discs where a special form of T root is adopted

in order to keep the stresses within the desired limits. These two rows of blading, the longer of which is 16 in., are of special shape, calculated to secure high efficiency and maximum strength.

The high-pressure rotor is carried in two bearings, and a flexible coupling is fitted between it and the first low-pressure rotor. The position of the high-pressure rotor is fixed by means of a Michell thrust block at the steam inlet end, but gear is provided for adjusting the position of the thrust block itself in an axial direction. By means of this adjusting gear, which is operated from outside the pedestal, the clearance between the blade shrouding and the diaphragms can be set is made to ensure their correct position, and to receive any slight thrust. This takes the form of a double Michell thrust bearing, one at each end of the solid coupling uniting the two low-pressure rotors ; the end of each coupling sleeve is ground to a bearing face which runs in contact with the Michell pads. The coupling flanges with their bolt heads and nuts are enclosed by a fixed oil and windage casing. The two bearings on either side of this coupling, together with the coupling and guard, are housed in a cast-iron cradle which fits into the lower half of the pedestal which supports both of the bearings on the lower portion of the exhaust chambers.

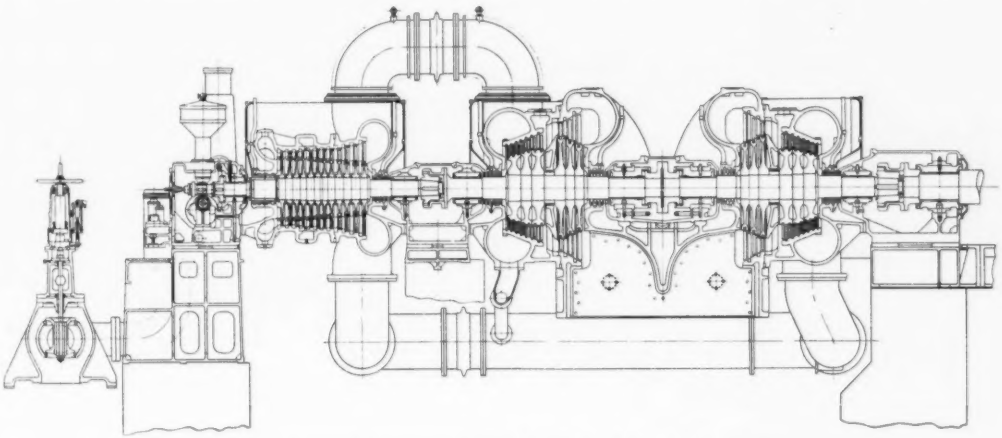


Fig. 3.—Sectional arrangement of 30,000-kW., 3,000 r.p.m. Turbine.

to any predetermined figure, an indicator being provided which shows the amount of clearance in thousandths of an inch. For dismantling purposes the adjusting gear can be slacked back, giving large clearances and so preventing damage to the shrouding when lifting the top half of the casing.

The coupling between the h.p. rotor and the first low-pressure rotor is of the tooth type. A half sleeve with internal teeth is bolted to the flanged end of the low-pressure rotor and engages with a toothed attachment on the high-pressure rotor shaft.

Although the two low-pressure rotors are self-balancing axially, as already described, provision

Between the second low-pressure turbine and the alternator, there is a flexible coupling similar to that between the high-pressure and first low-pressure rotors. The pedestal containing this coupling, together with the end bearing of the low-pressure rotor and the first bearing of the alternator, is mounted on the alternator bedplate.

All the steam glands are of the carbon ring type, with the exception of that at the steam inlet end of the high-pressure rotor, where a labyrinth gland is employed.

On plant of this description a thoroughly reliable oil supply is essential. This is provided by a main oil pump of the gear type driven from the steam end of the high-pressure rotor through

worm gearing, and an auxiliary pump of the centrifugal vertical-spindle type driven by a small steam turbine. The latter is brought into action automatically by an oil relay when the oil pressure falls below a certain value.

From the boiler house to the turbine are two 14 in. diameter pipes, each fitted with an isolating valve. Steam passes from these to a single separator and thence by separate 14 in. pipes to the two steam chests on each side of the turbine ; both of these pipes are controlled by the main stop valve that is mounted on top of the separator. The throttle valves are actuated in the usual way through oil relays controlled from the governor and pilot valve, but the two throttles are mechanically interlinked.

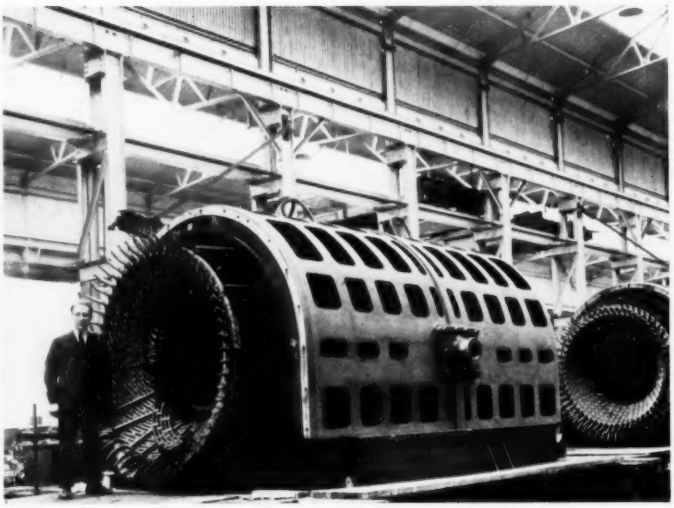


Fig. 4.—Stator of 30,000-kW., 3,000 r.p.m., two-phase Alternator for West Ham under Construction.

An emergency governor of the out-of-balance ring type is mounted on the turbine shaft. If this comes into action due to overspeed, or if the oil pressure fails, the throttle valves and main stop valve are closed automatically.

The single-shell condenser is one of the largest installed in this country, and contains special patented features ; the division between the two water flows is vertical and steam enters both flows simultaneously. It operates in conjunction with cooling towers and maintains a vacuum of 28.3 in. Hg. (bar. 30 in.) when supplied with cooling water at 75° F. The overall dimensions are approximately 14 ft. diameter by 22 ft. 6 in. long.

Duplicate two-stage extractors are installed, each capable of the full duty, and the condensate is withdrawn by a vertical spindle pump which is also of the two-stage type and duplicated.

A simple feed system has been adopted em-

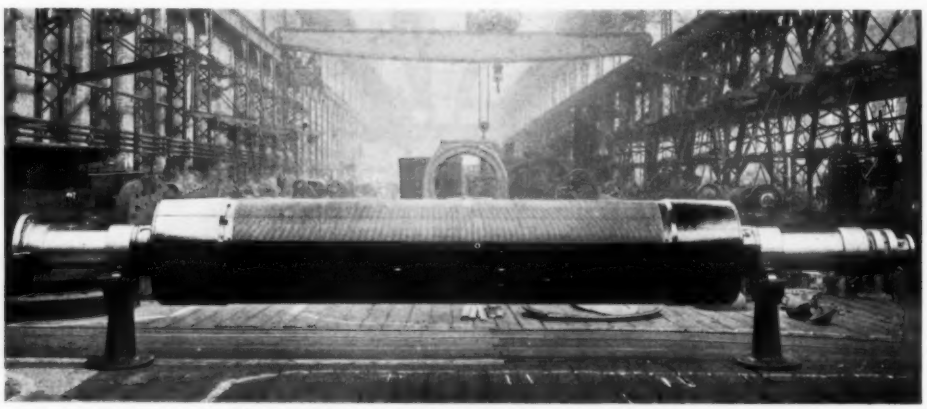


Fig. 5.—Rotor of 30,000-kW., 3,000 r.p.m. Alternator.

bodying two-stage bleeding, and a drip cooler, and the final feed temperature is 214° F.

The feed heaters are similar to the "English Electric" heaters installed in many stations, dan with the exception of the drip cooler are of the vertical type. Independent triple-effect evaporators are installed, in duplicate, and there are one motor-driven and two steam-driven feed pumps connected to ring suction and delivery mains.

The alternator of the West Ham set has a maximum continuous rating of 37,500 kVA. at 0.8 power factor, and is wound to generate 50-cycle, two-phase current at any pressure between 6,000 and 7,000 volts. It is ventilated on the closed-circuit system by means of a motor-driven fan and an air cooler, and the arrangement of the air passages on the multiple-inlet principle ensures a high degree of uniformity in the temperature of all parts.

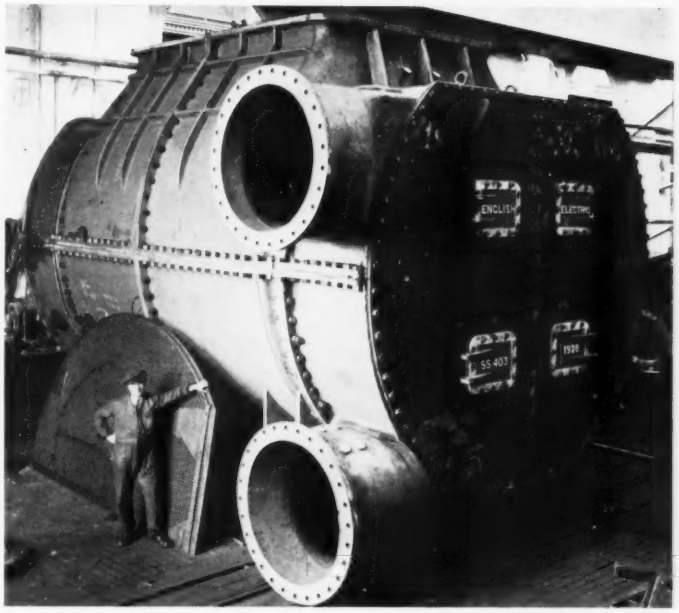


Fig. 6.—The single-shell Condenser for the 30,000 kW. Turbo-alternator Set at West Ham.

All details of the mechanical and electrical design follow the usual practice of the Company, based on their long experience in building machines of this class. Special mention may be made of the construction of the rotor end windings. The end of each coil is completely insulated to withstand the test pressure of 3,500 volts to earth, and a sheath of thin sheet metal is then applied. In assembling the windings, metal packing pieces are inserted between the individual end coils so that the whole becomes a practically solid mass. The end bells are then shrunk on and the rotor completed in the usual way. The exciter is driven directly from the alternator through a flexible coupling.

The new plant at Bradford has been constructed to the specification and under the supervision of Mr. Thomas Roles, M.I.E.E., the Chief Electrical Engineer of that city. The contract for the West Ham unit was undertaken in accordance with the requirements of Mr. F.W.Purse, M.I.E.E., formerly Engineer and Manager of the Electricity Department, and now Chief Electrical Engineer of the London and Home Counties Joint Electricity Authority ; the installation was completed and set to work under the supervision of his successor, Mr. J. W. J. Townley, A.M.I.E.E.

The Hydro-Electric Power Plants of Scotland.

Lochaber—Kinlochleven—Loch Rannoch—Bonnington—Stonebyres.

(The descriptions of these plants are published by kind permission of the several companies from whom the contracts were received; grateful acknowledgment is made to the British Aluminium Company, and especially to Mr. W. Murray Morrison, Director and General Manager; to Messrs. Balfour, Beatty and Company; and to the Lanarkshire Hydro-electric Power Company.)

The whole of the modern water-turbines of large output that have been installed in Scotland since the War have been manufactured by this Company; these plants have an aggregate capacity of 114,000 h.p. In addition, the Company has reconstructed older turbines at the Kinlochleven station to give a total output of 29,000 h.p. All the electric generators for these plants, with the exception of those for Loch Rannoch, are also of " English Electric " manufacture. This article describes the plant recently installed at Lochaber and Loch Rannoch, and the reconstruction work at Kinlochleven, and to complete the survey reference is made also to the two stations on the Falls of the Clyde, full particulars of which have already been published.

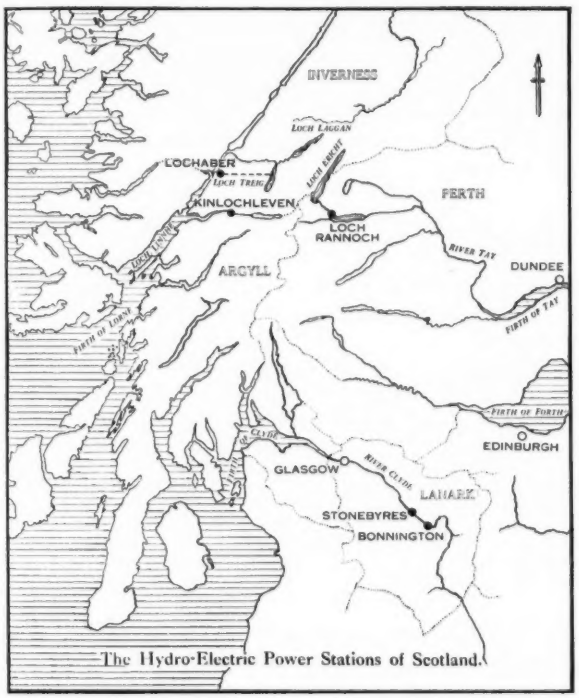
The Lochaber Power Station of the North British Aluminium Company.

The first section of the Lochaber Power Plant of the North British Aluminium Company was put into operation in December, 1929, and a visit of inspection was made by H.R.H. the Duke of York, in July, 1930. It constitutes the largest hydro-electric undertaking in Great Britain. The successful completion of this important industrial enterprise reflects great credit upon the British Aluminium Company and its subsidiary company. Some indication of the care and attention to detail that have been given to every part of the work is afforded by the spacious lay-out and handsome finish of the power house, a good general view of which is reproduced as the frontispiece.

It may be recalled that the water is derived from Loch Laggan and Loch Treig, and numerous streams in a catchment area of 303 square miles, and is conveyed through a lined tunnel 15 miles long and 15 feet in diameter.

The civil engineering works have already been described elsewhere*, and it is proposed in this article to give some account of the five 10,000 h.p. main generating units, which, together with the control gear, were constructed and erected by the English Electric Company.

The high standard of reliability demanded in



The Hydro-Electric Power Stations of Scotland.

Fig. 1.

* *A Paper read before the Institution of Civil Engineers on November 18th, 1930, by W. T. Halcrow, Member. Also "The Engineer." Vol. 149, Nos. 3876, 7 & 8.*

Fig. 2. Lochaber Power House. On the left are seen the supply pipes, the tail-race, and the ventilating air inlets.

this plant may be judged from the fact that it has to be capable of running continuously for at least eleven out of twelve months at maximum load without the necessity of closing down for cleaning, oiling, or renewal of brushes.

Water is conducted to the power house by two pipe-lines, each 65 ins. in diameter where they enter the distribution system, and is finally conveyed to the turbines through five 42-in. flanged pipes. The branch system is so arranged that each pipeline permanently serves two turbines, and the fifth turbine can be fed from either pipeline by opening and closing auxiliary valves.

The supply to each turbine is controlled by an " English Electric " Cylindrical Balanced Streamline Valve having an entrance diameter of 42 in. and an exit diameter of 36 in. These valves possess the special feature of closure at a diminishing rate, which enables them to be closed under any emergency conditions with complete safety to the pipelines. The main and inner bodies of the valve together with the valve piston are made of cast steel and a dismantling ring of the same material is provided for easy removal and inspection of the valve. The valves are arranged for operation by water pressure, but provision is made for electric control if this is required at a later date. All sliding surfaces in contact with the water are protected against rust by a coating of nickel. The five main valves are shown in Fig. 3.

The five main turbines are each designed for a maximum output of 9,600 h.p. under the minimum nett head of 650 ft. at a minimum speed of 237 r.p.m. They run at a speed of 250 r.p.m. under the normal nett head of 720 ft., and at 267 r.p.m. under a nett head of 800 ft. Figs. 5 & 6 show the details of one of the turbines, and Fig. 4 shows one of the runners. The runner carries 22 steel buckets attached to a cast steel disc by the " English Electric " patented one-bolt fastening which comprises a tapered forged steel bolt and a split bush, the inside of which is tapered and the outside cylindrical. The disc is attached to the shaft by means of a flange coupling ; this design allows of easy dismantling since the disc can be arranged with clearance fit instead of with interference fit.

The runner is fed by two jets, each 8½ in. diameter and spaced at an angle of 60 degrees, careful calculation having shown that a single-jet turbine would not be so economical and efficient owing to the large diameter jet that would be necessary, and the relatively high specific speed. The bearings are of the standard self-aligning type designed for automatic lubrication by oil rings, and, in addition, separate forced lubrication is provided by means of a small pumping set driven by an impulse turbine. The same pumping set provides oil under pressure for the governor.

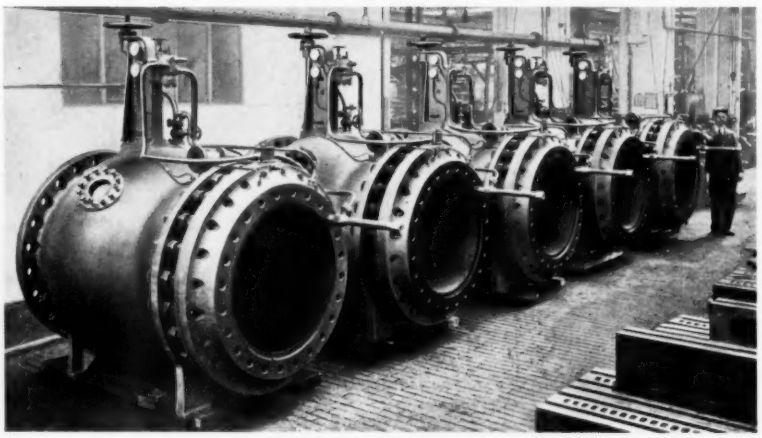


Fig. 3. The five Cylindrical Balanced Valves of 42"/36" diameter.

The turbine housing consists of a bedframe in five parts, a cast-iron cover, and a pit armouring of sheet steel; great care has been taken to obtain a strong anchorage, the bedframe being extended well below the floor. For rigidity of the whole unit the turbine and generator bedframes are securely bolted together, thus forming one solid block. Cast-iron was selected for the turbine cover since it ensures great stiffness and strength and is best adapted for use with a two-jet design.

The turbine spears and nozzles are carried by the inlet bends and the nozzles are fitted with renewable bronze mouthpieces. The servo-motor which controls the two spears is attached to the upper inlet bend, and is thus easily accessible for supervision and dismantling.

The governor is of the Company's standard oil-pressure type, and the actuator is directly driven from the main shaft through gearing. Governing is effected by deflectors since the particular duty for which the units are required does not call for the close regulation given by the Seewer diffuser, which is so essential for a normal hydro-electric plant.

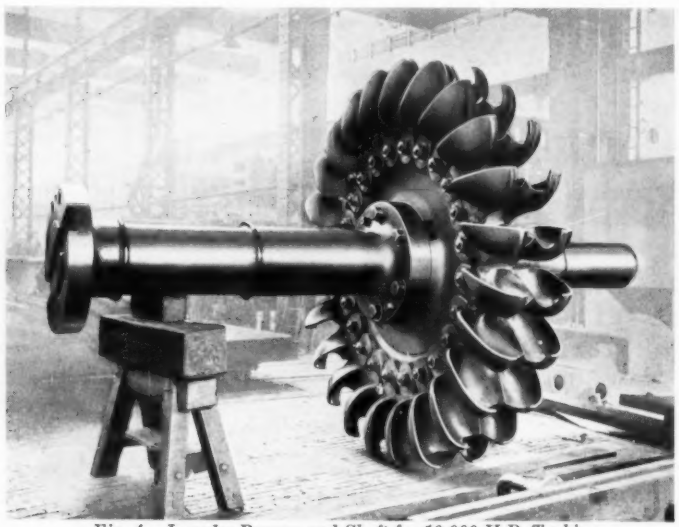


Fig. 4. Impulse Runner and Shaft for 10,000 H.P. Turbine.

In order to fulfil the special requirements the governor is arranged to come into operation only when the variation in load causes the speed to alter by 10 per cent. above or below the efficient speed for the available head, for which head the position of the spears has been set by hand. When the speed reaches a value 10 per cent. above

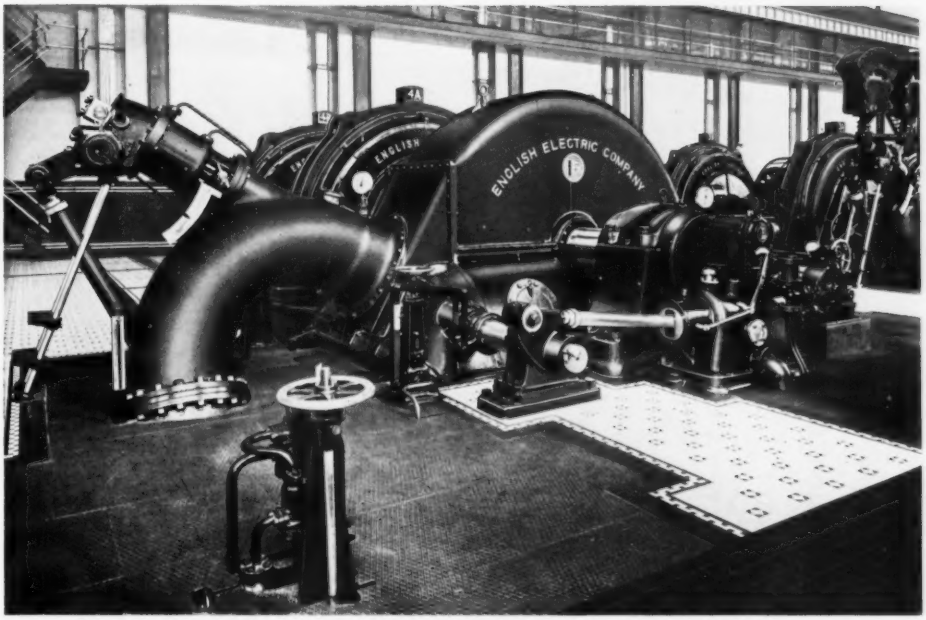


Fig. 5. View of Turbine showing Governor, Actuator and Upper Inlet Bend with Servomotor.

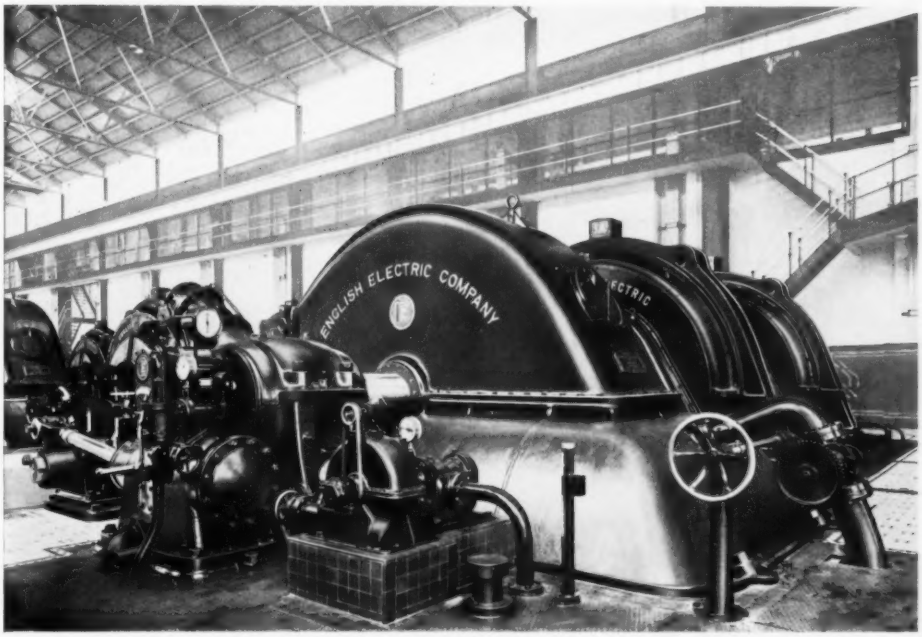


Fig. 6. This view shows the Turbine-driven Oil Pump and the Braking Nozzle.

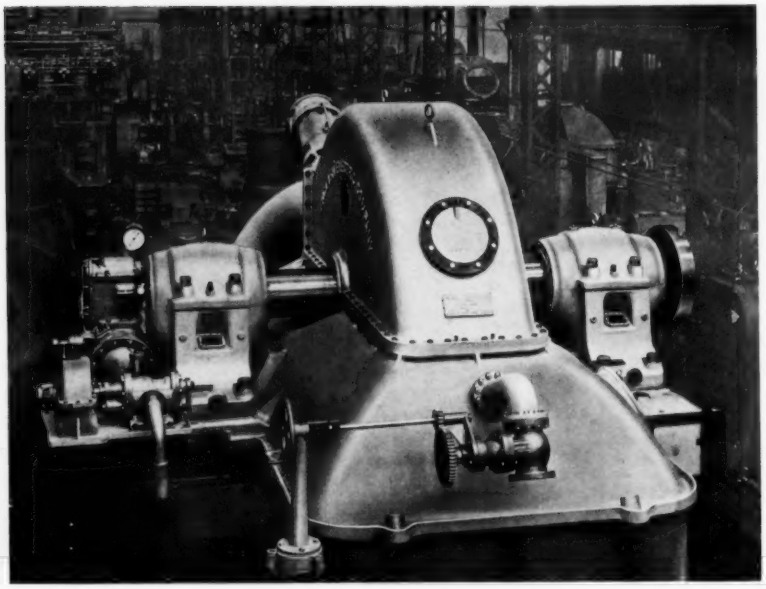


Fig. 7.
10,000 H.P. Impulse Turbine erected at Rugby Works.

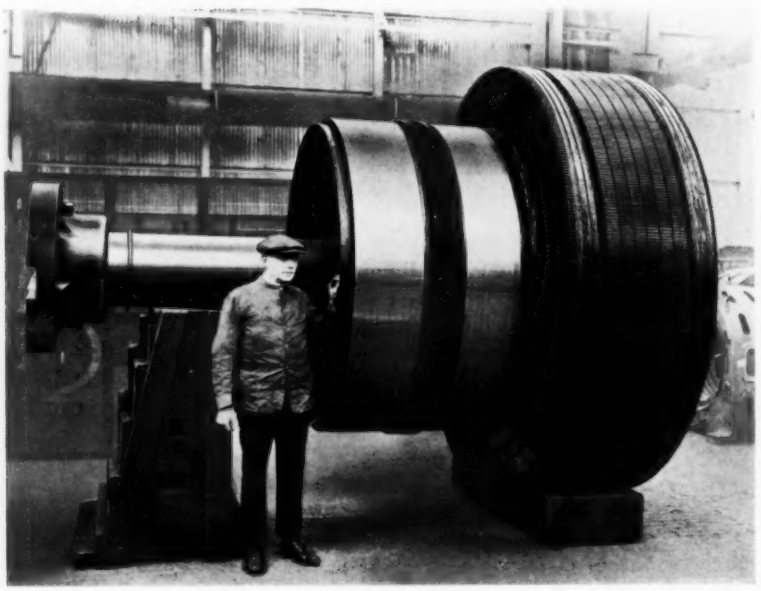


Fig. 8.
Armature of one of the Twin 10,000-ampere 300-volt Generators.

normal, the deflectors close and prevent the jets from striking the buckets, this condition remaining as long as the speed rise exceeds 10 per cent. The spears automatically follow the deflectors by closing with a slow movement which avoids undue pressure rise in the pipeline. When the speed rise falls below 10 per cent., the governor causes the deflectors to open and this is followed by the automatic opening of the spears.

On the other hand, when the speed drops 10 per cent. below normal, signifying that more water must be admitted to the turbine, the governor by closing electrical contacts causes an alarm to be sounded, and the attendant then opens the spears, thus raising the speed to the value necessary for the best efficiency.

The oil pump is made in two parts, one for bearing lubrication, and the other for supplying oil-pressure for the governors, and this arrangement is very convenient as the same oil is used for both purposes, and the same prime mover deals with the whole oil service of the set. In order to secure the utmost reliability the oil systems are interconnected so that any unit can be supplied with oil from the adjacent unit. An oil-pressure alarm device is provided to give warning when the oil pressure falls below 150 lbs. per sq. in.

To bring the set to a standstill as quickly as possible when it is shut down and thus prevent crawling, which is harmful to the bearings, each turbine is fitted with a braking nozzle controlled by a stop valve. This is connected to the pressure supply and causes a jet of water to impinge on the back of the buckets, thus bringing the rotating parts quickly to rest.

Each turbine drives a pair of direct-current generators each of which has a continuous maximum rating of 3,400 kW. at any speed from 237 to 267 r.p.m., the speed being varied from time to time to suit the available pressure of water. Fig. 9 shows one pair of generators with their exciter. The normal current output of each machine is 10,000 amperes at any voltage from 150 to 340, the normal voltage being 300. They are 24-pole machines with commutation poles, and are not compensated. The air gap under the main poles is graded from a minimum near the entering pole tip to a maximum at the leaving tip; the effect of this is practically to eliminate field distortion in the region of full load with a consequent large reduction in stray load losses. A fan runner is fitted at the back end of each armature, which is enclosed by means of an end-bell and cowl, the latter extending down to an air duct in the foundations. This air duct is

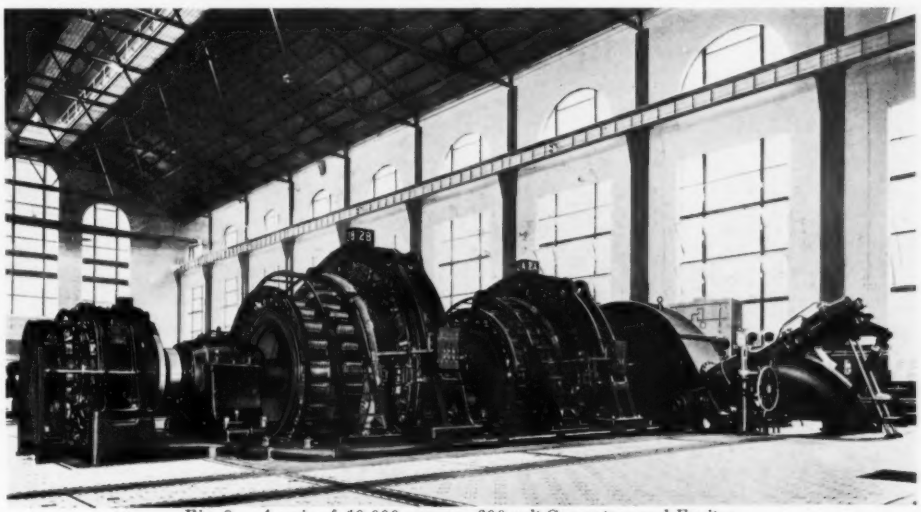


Fig. 9. A pair of 10,000-ampere, 300-volt Generators and Exciter.

carried to the outside of the station where a weatherproof air inlet is provided for each unit.

The machines have to run safely at the runaway speed of the turbines, i.e. at 86 per cent. above the maximum normal speed of 267 r.p.m. This rendered it impracticable to employ commutators with the bars in one piece, as the centrifugal stresses in the long bars on overspeed would have been excessive. Additional factors ruling out that design were the large wearing depth and low brush density required. Therefore the machines were built with two-part commutators, the segments in each half being carried between "V" rings forged from high-grade steel. The two sections are carried on a common cast steel hub mounted on an extension of the armature spider, to which it is keyed and bolted. Corresponding bars of the two sections are connected by copper strips arranged to form a fan which draws cooling air between the sections. The commutator construction is of the non-arch-bound type developed and perfected by the Company.

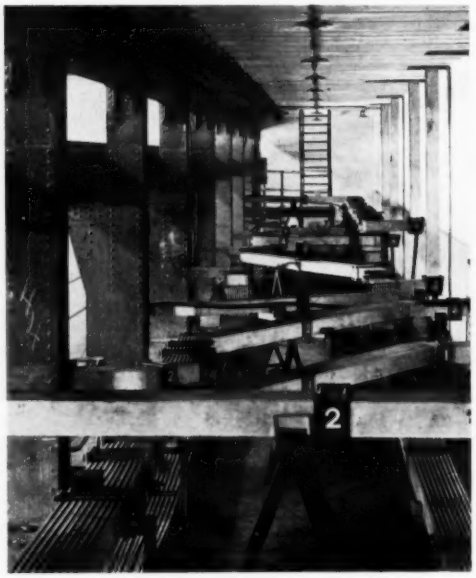


Fig. 10. The Aluminium Busbars are housed in a special corridor.

The brush arms are in the form of stiff girders arranged between the two cast-iron end-rings in a cagelike formation around each commutator. An insulated ladder fixed to the bedplate passes over the commutator and the brushgear of each machine, so that brushes can be replaced and adjustments made while running on load, the brushgear being arranged to facilitate this without danger to the operator or the machine. These ladders have a removable section at each side which can be lowered into the pit under the commutator to give access to the lower brush arms.

The armature core laminations are carried on a cast-steel spider, and clamped between cast-steel end-plates. All armatures are interchangeable both mechanically and electrically, the shafts being identical and designed to transmit the full h.p. of the turbine (i.e. twice the h.p. input to each generator of a pair). Any armature can be run in any field system without alteration of the brush setting. The generator bearings are of generous size and are provided with flood lubrication at low pressure; oil rings are fitted in addition to

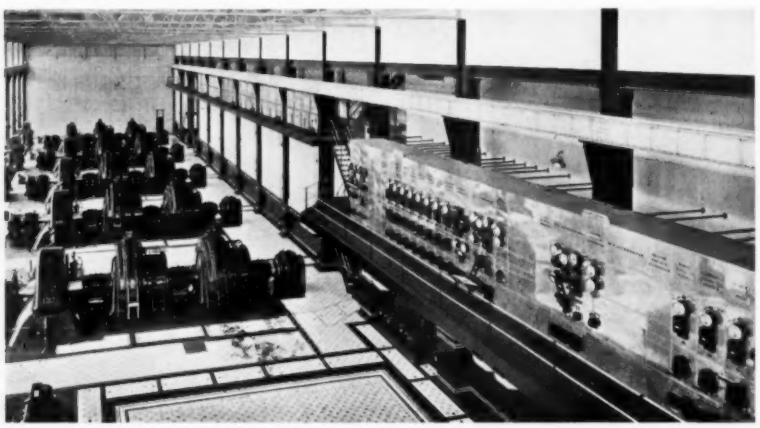


Fig. 11. Aluminium-fronted main switchboard and, beyond, the busbar corridor and gallery.

enable the machines to continue running in emergency without flood lubrication. The bearings are spherically seated.

Each generator is protected by an overload and reverse-power relay and an over-voltage relay. When a relay operates it de-energises the field circuits of the exciter and of all the generators of the group affected. Failure of the oil pressure or an abnormal fall in speed on any unit is notified by means of a lamp and an alarm device.

In addition to the direct-current control gear for the main sets the Company has also supplied low-tension A.C. switchgear, which can be seen on the right of Fig. 11, for controlling the small station auxiliary sets which supply power for the crane motors, the lighting, etc. A striking feature of the switchgear is that all the panels are of polished aluminium.

The busbars behind the switchboard are of aluminium, as also are the main current conductors shown in Fig. 10. A total of approximately 300 tons of aluminium bar is employed for this purpose.

Aluminium is used largely throughout the whole installation for a number of novel applications. The handrails are of aluminium, the expanded metal enclosing the busbar chambers and also many small details of the machines themselves. Aluminium paint is used for the roof trusses, and crane girders, and with the black painted uprights, cream walls, and black and white floor tiles, forms an artistic and pleasing colour scheme.

The power generated is, of course, used principally for the manufacture of aluminium, but some proportion is employed for lighting and power in the factories and in the village which has been built for the workers, and for operating wharf cranes and similar machinery. The distribution is by aluminium overhead lines.

The whole plant was erected expeditiously, and was put straight into commercial service with very little preliminary adjustment. The sets run very smoothly and silently and as will be seen from the illustrations they present a fine appearance.

Fig. 12. An Aluminium "Lead" and entrance to busbar corridor and gallery.

Reconstruction of the Impulse Water Turbines at Kinlochleven.

The English Electric Company has been closely associated for many years with the generating plant at the British Aluminium Company's Works at Kinlochleven.

In 1906 ten units were built, each consisting of two 1,000-kW. generators in tandem, making twenty machines in all, each machine giving a normal current of 4,000 amps. at 250 volts, the speed being 300 r.p.m. In the same year two 500-kW. direct-current generators were supplied, each giving a normal current of 2,000 amps. at 250 volts and running at a speed of 400 r.p.m.; coupled in tandem to each of these machines was a 75 kW. generator to give a 500/550 volt supply for traction purposes. In 1915 a further order was completed for another 2,000-kW. tandem unit. All these machines have run continuously and satisfactorily during their long periods of service, and it was not until a few years ago that it was found necessary to equip some of the older generators with new commutators, which should give them a further long lease of life.

The ten tandem units ordered in 1906 were driven by turbines manufactured by Messrs. Escher Wyss & Co. but when in 1926 the British Aluminium Company decided to secure higher

efficiency by reconstructing one of these turbines on modern lines, the work was entrusted to The English Electric Company. The most important features of the reconstruction were the substitution of one jet for the two jets which actuated the original runner, and the supply of a completely new runner having 24 buckets instead of 22 buckets, the new buckets also being of considerably larger size. The single jet still allowed of a favourable ratio between the pitch circle diameter of the runner and the jet diameter, and the efficiency was increased by the use of one large compact jet instead of the two small jets of the original design.

The design of the new buckets was carefully studied in order to secure the best water flow for the different relative positions of the bucket and the jet and, in order to reduce friction losses the inside surfaces of the buckets were ground and polished and the centre edge or "splitter" was milled sharp to create a favourable angle for the diversion of the water. Fig. 15 shows a runner mounted at Preston Works for balancing and overspeed testing.

It was found possible to utilise the existing shaft, and the new runner disc was pressed on to it; the buckets are attached to the rim by means of the "English Electric" patented one-bolt fastening. A single inlet bend of large radius was fitted instead of the two existing bends necessitated by the two-jet design, and this led to a marked reduction in friction losses. Other new parts included a cast-steel spear with special bronze head, and nozzle mouthpiece of the same material, the shape of these parts being such as to obtain a smooth flow and so eliminate erosion.

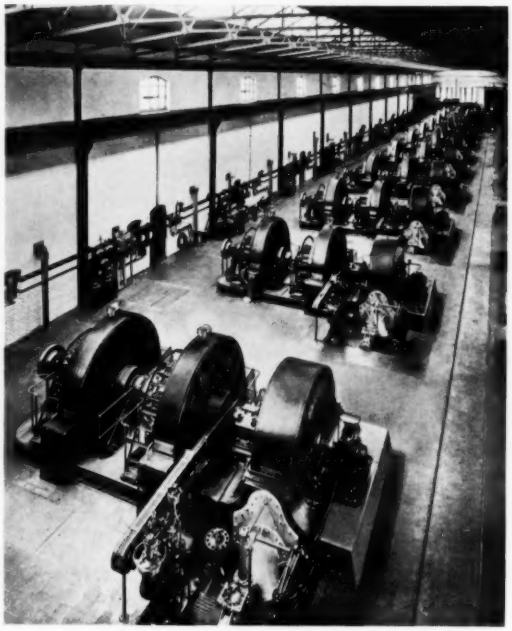


Fig. 13. Interior of Kinlochleven Power Station showing the reconstructed turbines.

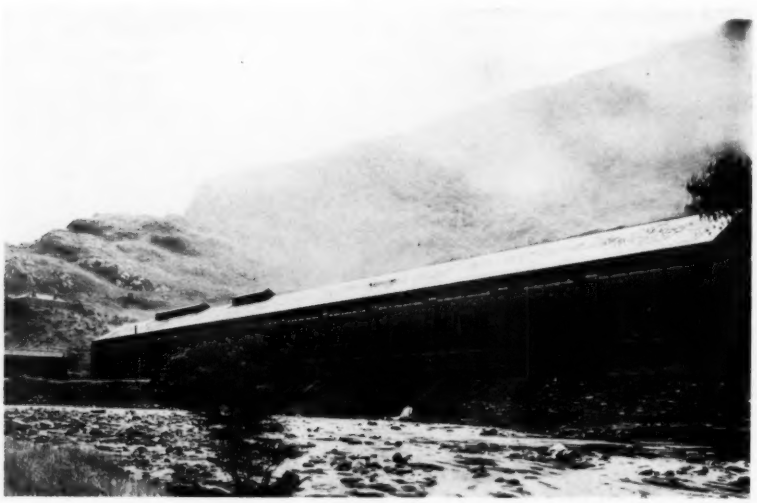


Fig. 14. Kinlochleven Power House.

A new cast-iron spear servo-motor was also supplied, and certain new bends and link-work, but the existing turbine casing, governor, relief valve, and bedframe (except for a new front section) were all retained. The reconstruction was

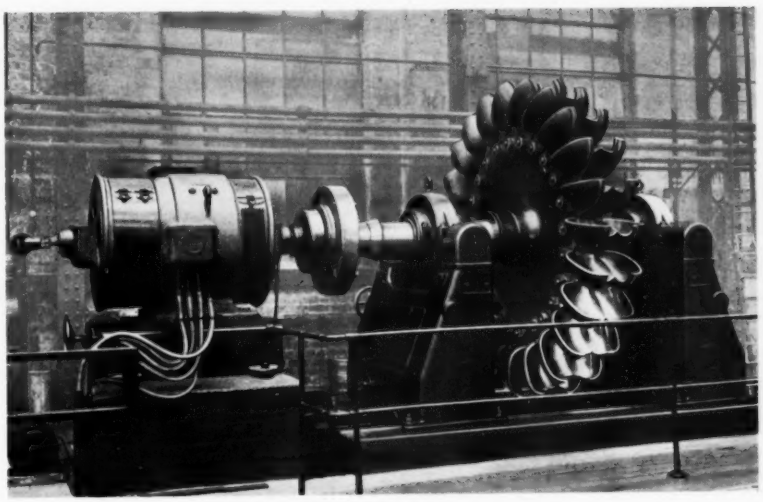


Fig. 15.
A new Impulse Runner for Kinlochleven on the Balancing Machine.

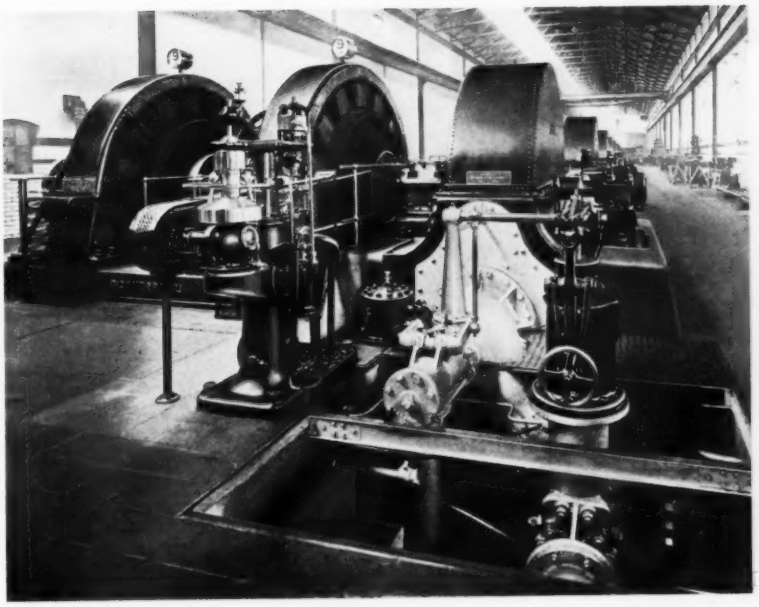


Fig. 16.
One of the reconstructed 3000 H.P. Turbines at Kinlochleven.

thus designed on the most economical lines consistent with obtaining the best possible increase in efficiency. In the view of one set shown in Fig. 16, certain of the new parts can be distinguished by their lighter colour.

On completion, the turbine was thoroughly tested for efficiency by the Pitometer method, a test by the same method having been taken on the turbine before reconstruction. The load was obtained by means of a water resistance, and the same instruments were used in both tests.

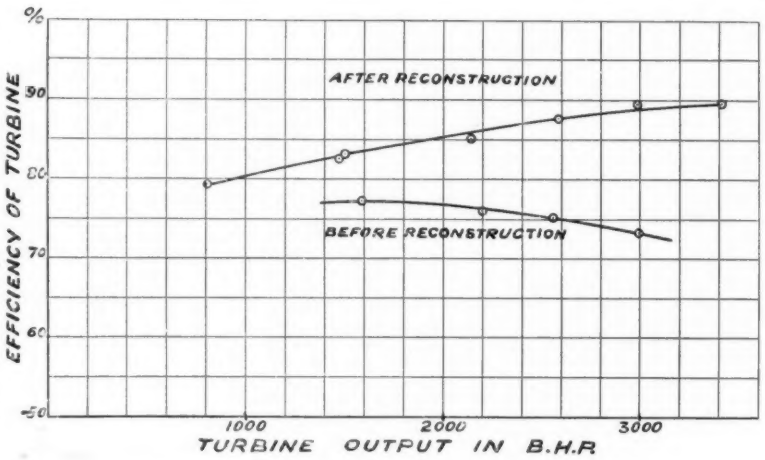


Fig. 17.—Efficiency Curves of Kinlochleven Turbines.

The full load efficiency before reconstruction was found to be 73.4 per cent.

The guarantees given for the turbine after reconstruction were :—

Maximum load	(3,200 h.p.)	85%
Full	,, (2,900 h.p.)	86%
$\frac{7}{8}$	,, ...	85.5%
$\frac{3}{4}$	,, ...	85%
$\frac{1}{2}$	,, ...	82%

The full-load efficiency obtained was 89.5 per cent., representing a gain of 16.1 points by the reconstruction, equivalent to a gain in power of 21.9 per cent. without any increase in water consumption.

The efficiency curves before and after reconstruction are shown in Fig. 17.

At the end of 1928 it was decided to reconstruct a further eight turbines on the same lines as the first reconstruction described above, except for a few minor modifications, and the work was again entrusted to this Company. It was decided to make the entire nozzle in bronze instead of the mouthpiece only, and the needle tip in stainless steel instead of bronze. Bronze liners were also provided for the spear servo-motor.

In other respects the work was practically identical with that carried out on the first set. The whole of the work on the eight turbines was recently completed and a view of the Power Station showing the reconstructed turbines and the original generators is reproduced in Fig. 13.

The Grampian Hydro-Electric Scheme.

The completion of the first stage of the Grampian Hydro-electric scheme will be marked by the putting into commission of a power station on the shore of Loch Rannoch. This station has been constructed to contain two 22,000 h.p. generating sets, with provision for a third set later. It utilises the water stored in Loch Ericht and the difference in level between Loch Ericht and Loch Rannoch, the net head available for the turbines varying between 396 and 515 feet. The turbines are of the vertical reaction type ; they run at 500 r.p.m. and give their full-load output of 22,000 h.p. under a net head of 515 feet. In order to allow for the varying head the efficiency curve from 50 per cent. to 100 per cent. of full load is very flat, the peak value corresponding to 80 per cent. of full load under a head of 465 feet. Definite efficiencies have been guaranteed on a penalty and bonus basis.

Fig. 18 shows the general arrangement of the plant in the station. It will be seen that a two-floor type of construction has been adopted with

the turbines located on the lower floor and the generators and the turbine governing apparatus on the upper floor. As the vertical type of set employed is exceedingly compact, the ground area covered by the power station is quite small in relation to the total generating capacity.

Fig 19 shows the two turbines partly assembled during manufacture at Preston Works ; the spirals are of cast steel and are heavily stayed. As indicated in Fig. 19, the gate apparatus mounted on the spirals is arranged with particular regard to accessibility, the design allowing the individual guide vanes to be lubricated and adjusted from outside while the turbine is in service. The vanes are protected against obstructions in the usual way by carefully designed breaking links. The relief valve, which is of the " English Electric " cylindrical balanced type, forms a direct prolongation of the spiral casing ; the connecting rods between the gate apparatus, the relief valve mechanism, and the governor servo-motor are of exceptionally heavy construction to ensure the complete absence of " lost motion." An 11 in. solid way-shaft transmits the motion of the governor servo-motor from the upper to the lower floor.

Special alloy bronze has been used for the runners, and it is anticipated that they will give continuous service for many years. They are perfectly balanced and before leaving the Works were tested to the maximum overspeed of 975 r.p.m., or nearly double the normal running speed. Provision is made on the turbines for the easy dismantling of the upper part of the draught tube in order to allow the runner to be taken out on a truck which runs on rails to a point directly under an opening in the upper floor. The runner can then be lifted through the opening by means of the station crane. The runner is coupled by a short, stiff turbine shaft to the generator shaft above, both shafts having been carefully fitted together at the generator manufacturer's works before despatch to site.

The whole weight of the rotating parts of the turbine, as well as the downward component of the hydraulic thrust, is taken by the generator thrust bearing. A single turbine guide bearing is provided, however, this being of the usual white-metal lined, oil-lubricated, water-cooled type protected by a thermostat which forms part of the station automatic system. The oil supply is furnished either by hand pump, gear-driven pump or motor-driven pump. The hand pump is used for starting up and normally the gear-driven pump is used when running, the motor-driven pump serving as a standby.

The super-sensitive automatic oil-pressure governor is of the most modern " English Electric " type. This governor is fully standardised, the individual parts being built to jig within fine limits of accuracy, and held in stock. Working in conjunction with the cylindrical balanced relief valve, it gives exceedingly close

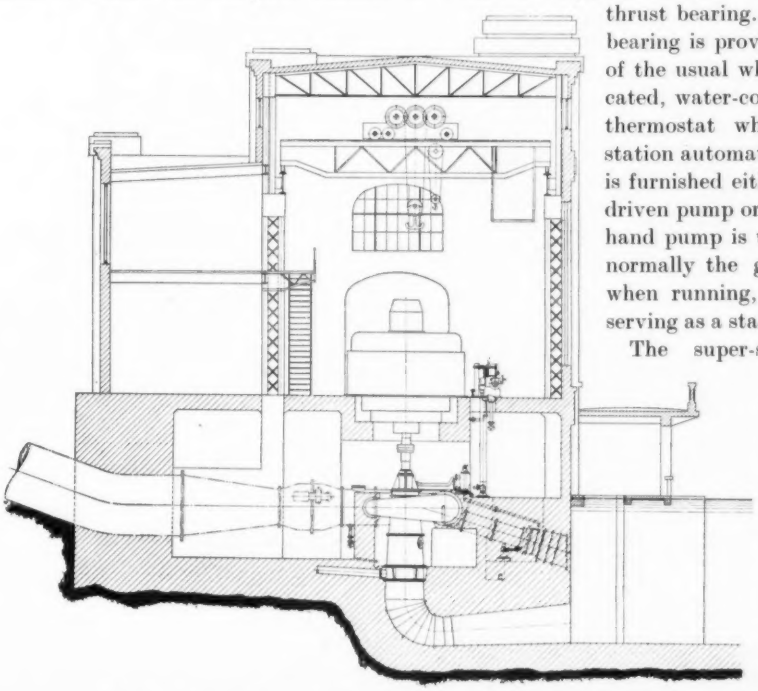


Fig. 18.—General arrangement of Power Station at Loch Rannoch.

speed regulation and ensures that the pressure rise in the pipeline is limited to a maximum of 10 per cent. under all conditions of reduction of load on the generator. The governor is actuated entirely by oil pressure obtained from a receiver that is fed by a motor-driven pump. If the oil pressure were to fail the governor would automatically close down the set. Similar automatic devices are installed to ensure shutting down on the occurrence of over-speed, or underspeed, or on failure of the governor belt drive. Local control of the governor can be effected manually and remote control by means of push-buttons on the main switch board. The latter provision greatly simplifies carrying out the operations of synchronising and load adjustment.

Fig. 19.—Spiral Casings of two 22,000 H.P. Reaction Turbines for Loch Rannoch.

The turbines were built to the order of Messrs. Balfour, Beatty & Co., Ltd., who were responsible for the construction of the Rannoch Station and the large civil engineering works which the scheme has entailed.

The Lanarkshire Hydro-Electric Power Scheme.

This scheme was fully described in the technical press towards the end of 1927, but in view of its importance and its continued success in operation it will be of interest to recall its main features. The project was first referred to in the report issued by the Water Power Resources Committee in 1921 ; work was commenced in 1924 under the authority of the Lanarkshire Hydro-electric Power Act. The contract for the civil engineering works was placed with Sir William Arrol & Co., and that for the whole of the generating plant, switchgear and transformers with the English Electric Company, who acted generally as hydraulic engineering advisers.

Although a scheme of this character had not been executed before in this country, and in spite of the serious delays caused by the coal strike of 1926, the work proceeded without serious incident and the stations were started up in 1927 ; up to the present date they have generated considerably more than 200,000,000 units. As an example of an all-British Hydro-electric undertaking, the works created great interest, and in 1928 the Institution of Electrical Engineers made a visit to them a special feature of their Annual Summer Meeting in Scotland.

The scheme utilises the three Falls of Clyde, namely, Bonnington, Corra Linn and Stonebyres, and power is generated at two stations only a short distance apart at Bonnington and Stonebyres.

which are connected in parallel with the steam stations of the Clyde Valley Electric Power Company. Normally, the plant runs continuously at maximum load, utilising all the water available, and in this way reduces the demand on the steam stations with considerable resultant economy.

Bonnington and Stonebyres derive their power from net catchment areas of 331 and 385 square miles respectively, the average rainfall over both areas being 43 inches per annum. Automatic tilting weirs are provided at both intakes, and these weirs maintain, within specified limits, a constant water level. From the intakes the water is conducted to the forebays through tunnels, 10 ft. diameter for Bonnington and 11 ft. for Stonebyres, which terminate in surge tanks. From the latter two 6 ft. 6 in. diameter pipelines lead to the power houses, each pipeline serving one generating unit. The two Bonnington pipelines, 800 ft. in length, terminate in streamline cylindrical balanced valves of " English Electric " patented design. At Stonebyres the arrangement is similar except that owing to the shortness of the pipeline (only 115 ft.) cylindrical balanced main valves are unnecessary.

Fig. 20.—Bonnington Hydro-Electric Station on Falls of Clyde.

Each power station contains two vertical reaction water turbine alternator sets constructed to run at 375 r.p.m. and to give a three-phase, 11,000-volt, 25-cycle supply. The units at Bonnington operate under a gross head of 189 ft. and have an output of 4,920 kW. each, while at Stonebyres the gross head is 97.5 ft., and the output of each set is 2,840 kW. The lay-out of the two stations is practically identical, and is of the one-floor type, which is strongly advocated by this Company for vertical units, in preference to the two or three-floor arrangement, on account of the great accessibility of all parts. From the general view of Bonnington Power Station in Fig. 20 it will be seen that the design has architectural merit and that the beauty of the landscape has been largely preserved. A view inside this station is shown in Fig. 21.

The generators are supported by reinforced-concrete pedestals built round heavy cast-iron tapered frames, the lower parts of which are bolted to the turbine speed rings. The spiral casings are of welded steel boiler plate, made in halves and finally welded together at site. The gate apparatus, consisting of cast-steel guide vanes connected by levers and links to a regulating ring, is controlled by a servo-motor and standard oil-pressure governor. The runners are constructed of steel plate vanes cast into a steel crown and a rim, and are bolted to flanges at the end of the turbine shafts.

At Bonnington, owing to the length of the pipeline, automatic relief valves of the cylindrical balanced type are provided, which discharge the water in the form of a hollow cone, causing it rapidly to lose its kinetic energy and to fall into the tailrace as a fine spray.

The generators are provided with thrust and guide bearings; the former is carried on the

bracket secured to the frame, and is surrounded by an oil bath and is water-cooled. The stators are made in halves to facilitate transport, and the rotors consist of cast-steel bodies, shrunk on the shafts, with dovetail grooves for carrying laminated steel poles. All the rotating parts are designed to withstand 90 per cent. overspeed.

The 11,000-volt switchgear also is of " English Electric " manufacture and includes oil circuit-breakers with a rupturing capacity of 250,000 kVA.

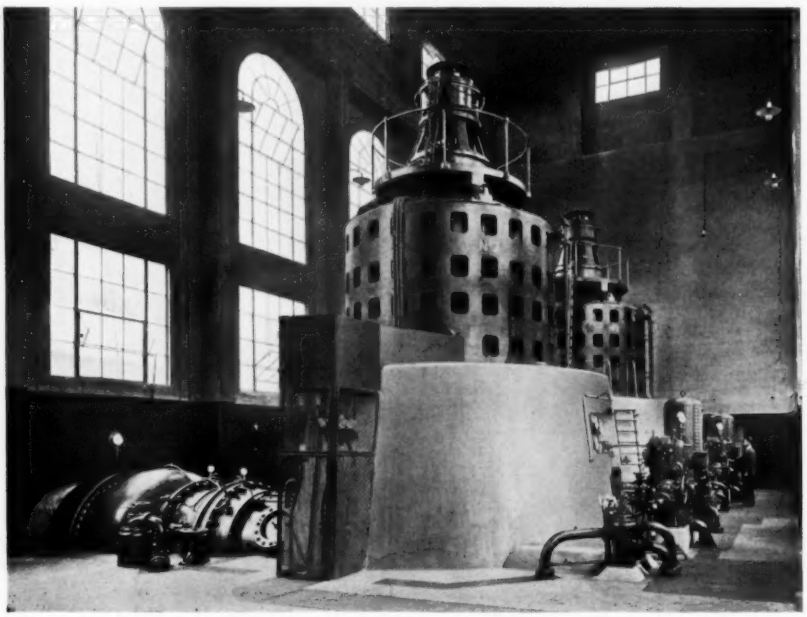


Fig. 21.—Two 7,000 H.P. Water Turbine and Alternators at Bonnington.

enclosed in moulded stone cellwork. The power is transmitted at 11,000 volts, and the drop in the transmission line voltage is compensated for by the provision of oil-insulated self-cooled booster transformers.

Conversion to 50 Cycles. As mentioned above, the alternators were designed for a frequency of 25 cycles. When it was decided to convert the Clyde Valley Power Company's supply to 50 cycles in accordance with the national policy of standardisation, it became necessary to reconstruct for this frequency. As a first step the conversion of one of the Bonnington alternators was undertaken; the order for the conversion of the other machine at that station and the two at Stonebyres has recently been received.

The Bonnington machines were rated at 6,150 kVA. at 0.8 power factor, 11,000 volts, 25 cycles, and had eight poles. The rating of the reconstructed machine, which has 16 poles and runs at the same speed, is 6,220 kVA. at 0.8 power factor, the current being supplied at 11,500 volts between terminals and 50 cycles.

The reconstruction involved the supply of an entirely new stator winding, but it was possible to use the existing stator core without modification. The winding is of the basket type connected in two parallel circuits, and the coils are entirely mica insulated. It is of interest to record that when the old coils were removed the insulation was in absolutely sound condition and free from any trace of ionization, or of swelling at the points where the coils cross the radial air ducts in the core.

The new stator coils having been prepared in advance of the dismantling of the machine, work was commenced on the 1st June and by the 17th July the new winding was complete. The only other modification made to the stator was the replacement of the cast-iron stator coil support rings by "Nomag" rings in order to eliminate the higher stray losses which would otherwise have occurred in this part at the higher frequency.

The rotor was returned to Stafford Works and the existing poles and coils removed. These poles were solidly fitted into dovetail slots milled in the eight flats of the cast-steel hub. Eight additional flats and dovetail slots were cut between those already existing. The sixteen new poles, consisting of sheet-steel laminations bolted between gun-metal end-plates, had been prepared in advance; they also are provided with dovetails, but owing to the much smaller centrifugal force of each pole, it was possible to use taper side-keys for securing them in the slots. The new field winding, like the old, is of bare copper strip, insulated with mica both between turns and from the metal spool on which it is mounted; it is designed so that the existing exciter is suitable without modification. New coil supports were fitted between each pole, and the original fans remounted on the rotor.

The reconstruction of the rotor was taking place whilst the stator was being re-wound on site. It was reassembled in the stator without delay, and the reconstructed machine was finally brought up to speed on the 18th August, only ten weeks after it had been shut down.

More Industrial Locomotives.

From time to time attention has been drawn in these pages to the extending use of electric locomotives for a wide variety of industrial haulage purposes, and an indication has been given of the progress in design and in the size of individual units. The special requirements of different industries and of operation under the most diverse labour and climatic conditions have been closely studied by the Company, and their experience of operating results confirms their earlier view that there is a wide scope for economy through the introduction of electric traction in

Fig. 1.—New Locomotive at Stafford Works hauling 120 tons of Transformers.

the majority of industrial undertakings of considerable extent.

The large unit illustrated in Fig. 3, has recently been added to the fleet of "English Electric" battery locomotives previously supplied to the War Office. This locomotive is of the double-bogie type for standard gauge and has a weight of 31 tons. It is equipped with four motors giving a maximum tractive effort of 15,000 lbs. at the tread of the wheels and 9,000 lbs. on the one-hour rating. It is believed to be the largest battery locomotive in operation in Great Britain.

The superstructure is of the central cab type, the batteries being contained in the two sloping ends. Each battery compartment has a cover that is removable in one piece; the covers are slid off by means of chain driven gear, so that in spite of their size and weight, it is a one-man job to open up the battery for examination.

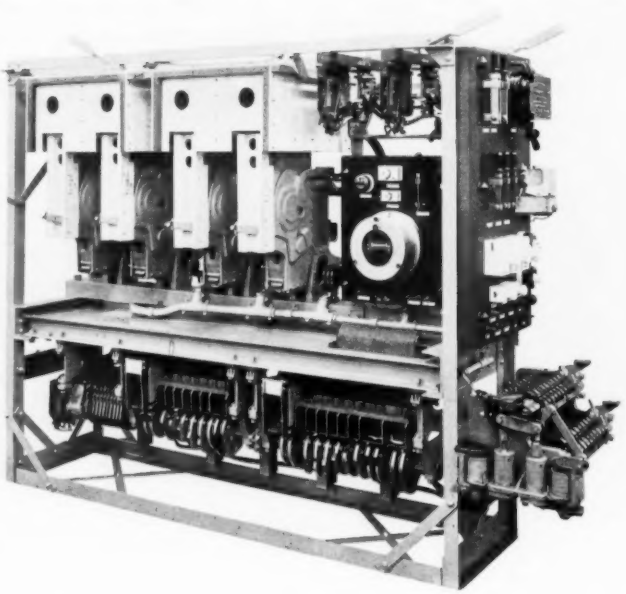


Fig. 2.—Control equipment of the locomotive shown in Figure 4.

The battery, which consists of 108 cells manufactured by the D.P. Battery Company, has a capacity of 1,000 ampere-hours at the 10-hour rate of discharge.

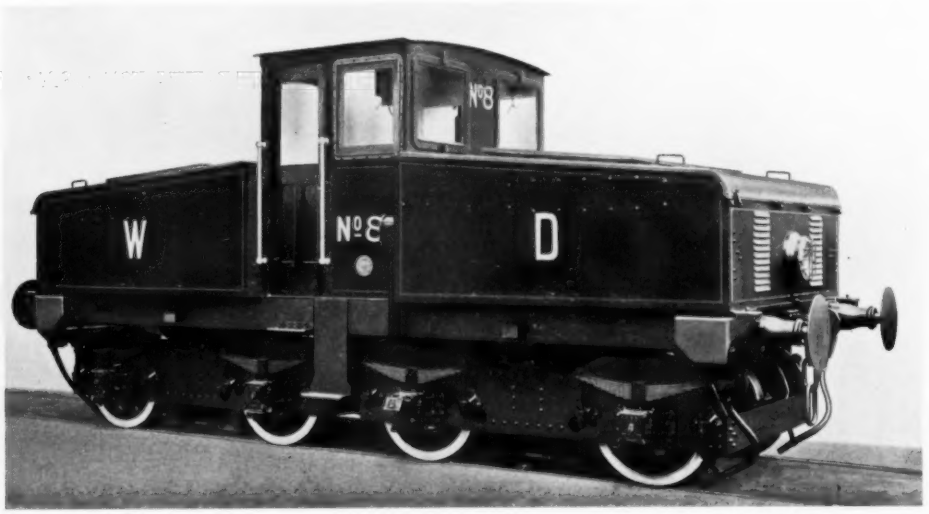


Fig. 3.—This 31-ton locomotive is probably the largest battery unit in Great Britain.

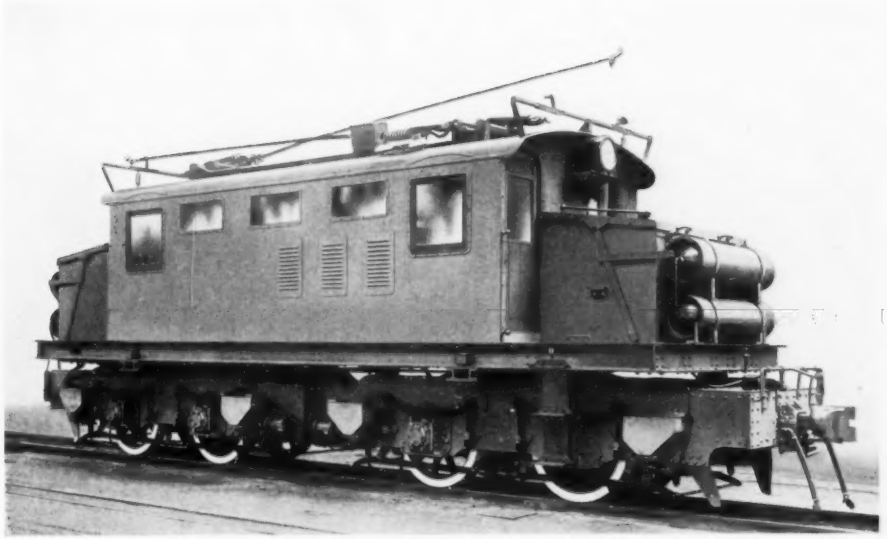


Fig. 4.—45-ton locomotive for the Peruvian Corporation.

Special features of the equipment are an axle-box mileage recorder, two ampere-hour meters for "charge" and "discharge," window wipers, and heavy plate-glass windows to withstand concussion.

A locomotive of some interest is one which has just been completed for the Peruvian Corporation Ltd. Although intended for private service, it is constructed for trolley operation and for handling both freight and passenger traffic. The unit, which is illustrated in Fig. 4, is of the double-bogie type and weighs 45 tons. It is operated by four 160-H.P., 550-volt motors. It has been designed to operate at first on a 550-volt line, but the equipment has been arranged so that at a future date the line voltage can be increased to 1,100 volts.

It will be seen that the superstructure is of box-type with short projecting ends; the latter house the electrically driven compressor and a motor-generator set to give 110 volts for the control and lighting.

There is a driving cab at each end and the control apparatus is mounted in the central portion on the centre line; the resistances are in two banks, one on each side of the locomotive, and the resistance compartments are fitted with louvres for ventilation. Fig. 2 shows the control apparatus, which is of the electrically-driven camshaft type, mounted on a self-contained framework which is fitted as a complete unit.

An interesting point about this locomotive is that it will operate high up in the Andes at an altitude of 13,000 feet above sea level, and during its journey to site it had to be transported across Lake Titicaca which is 12,540 feet above sea level. The locomotive has been built under the supervision of Messrs. Livesey Son & Henderson.

In Fig. 1 is shown a new locomotive put into service a short time ago at the Company's Stafford Works. This is a standard two-axle, 14 ton battery unit of the No. 3 type which is largely used for hauling trailing loads of about 120 tons in the vicinity of large works where there are no steep gradients. It is a type that has proved very serviceable for power stations and similar undertakings where train marshalling is carried out during six or eight hours each day.

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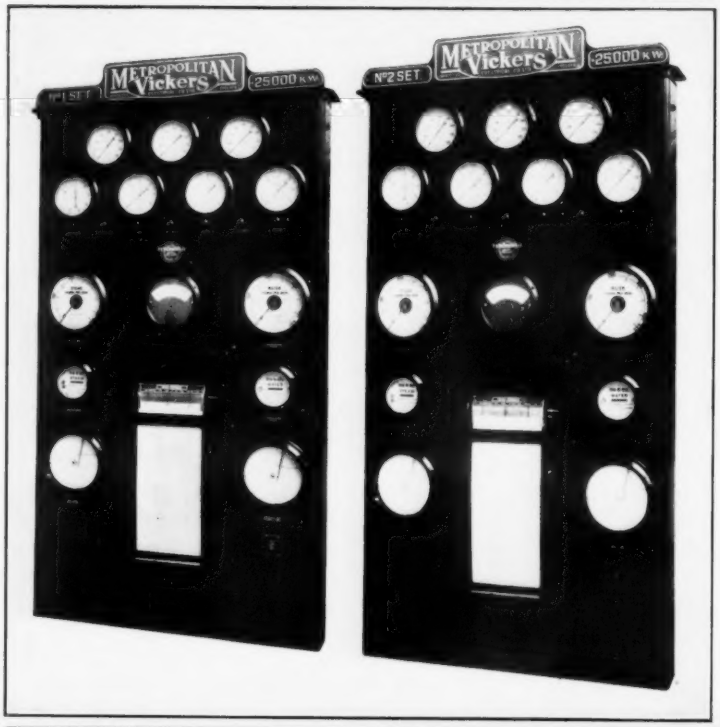

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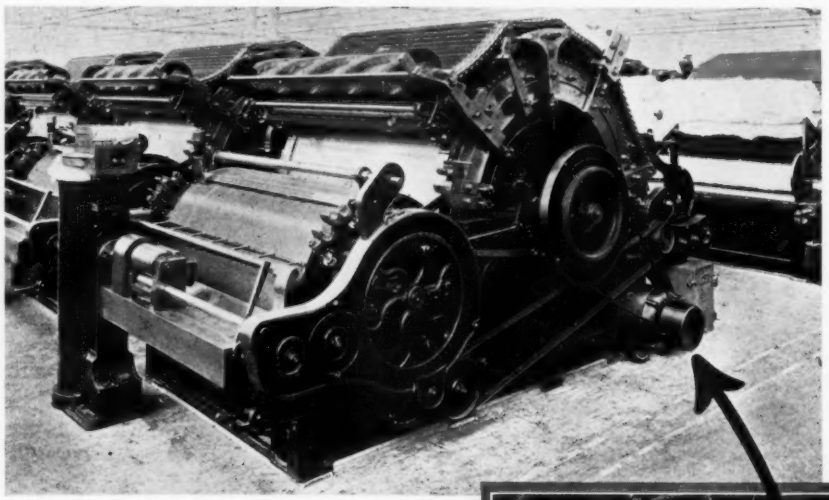

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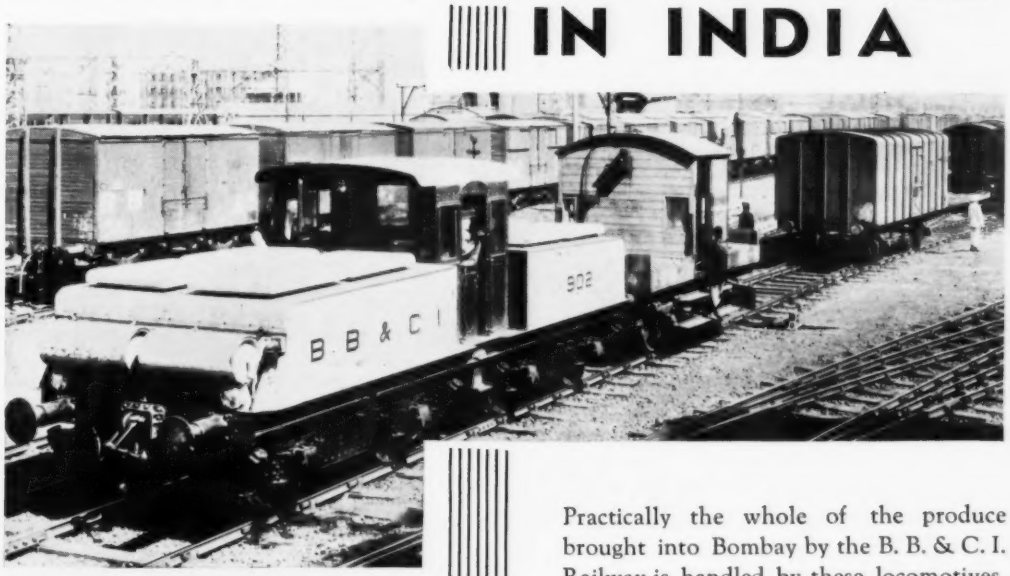

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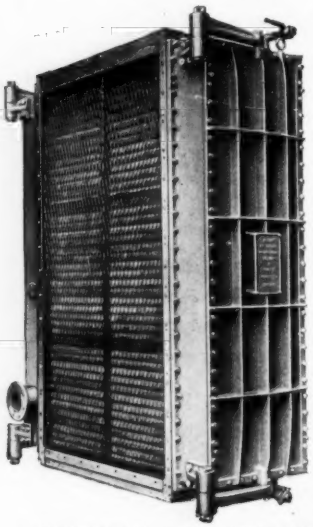

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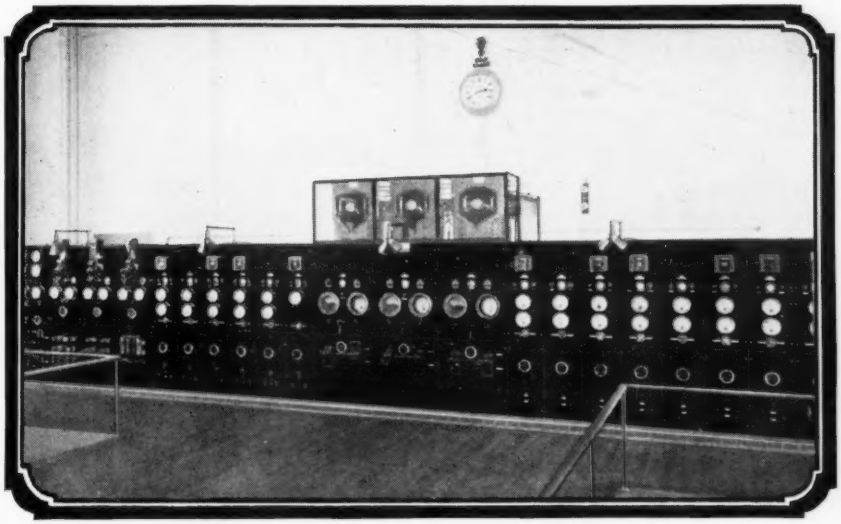

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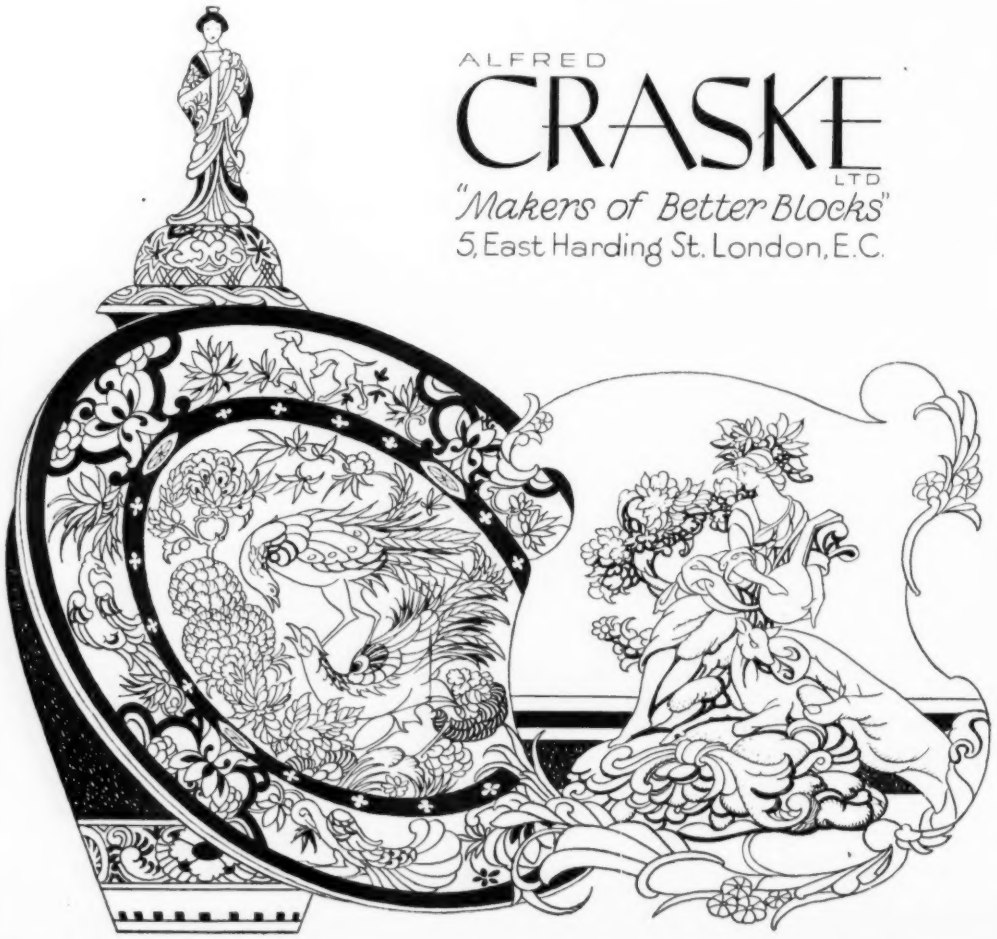

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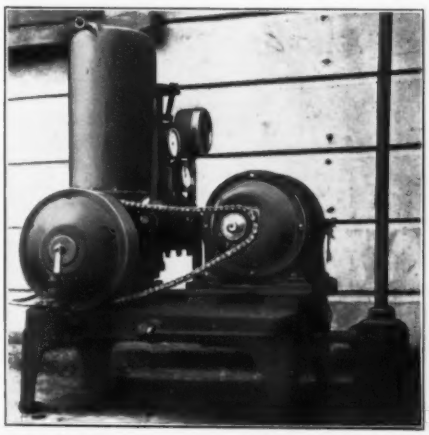

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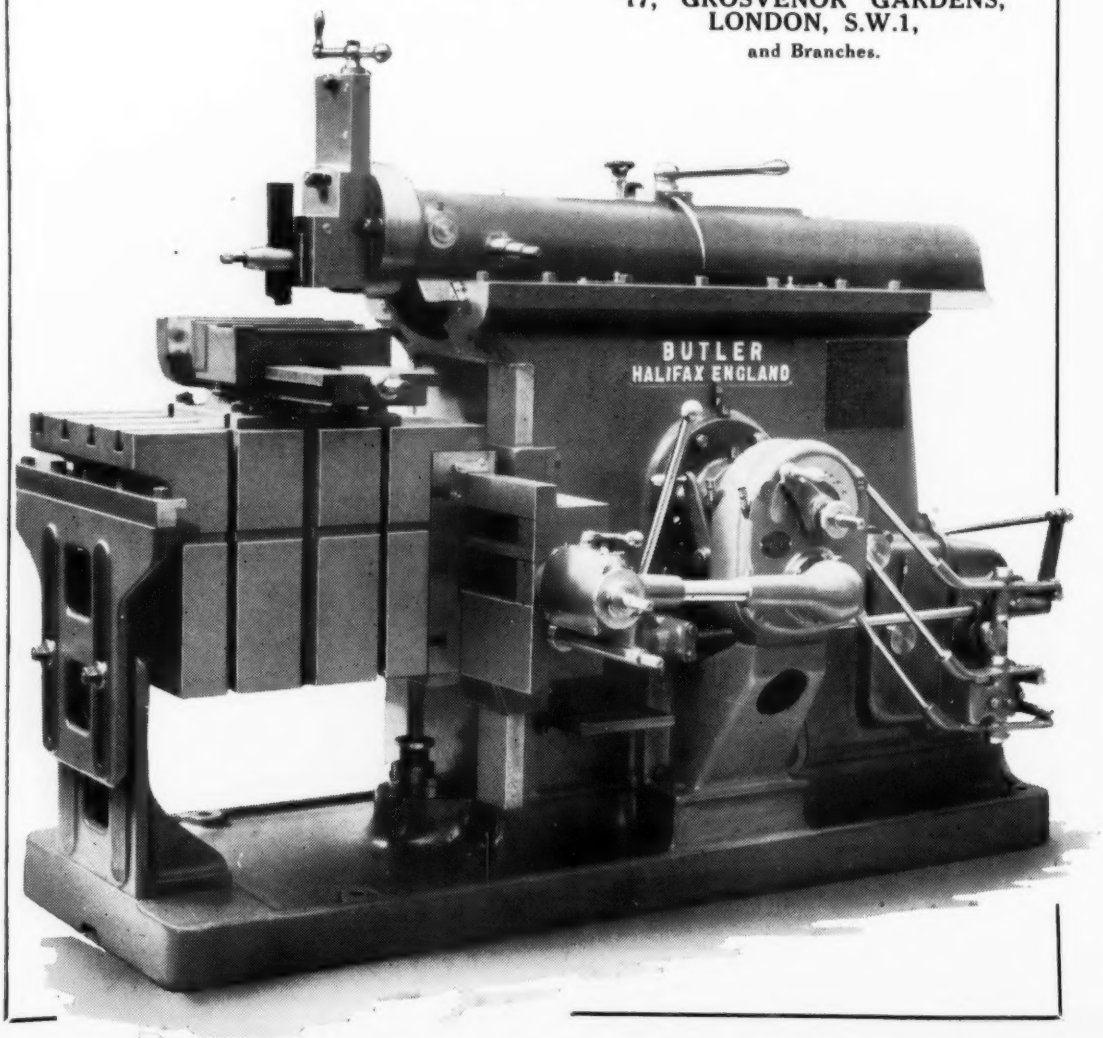

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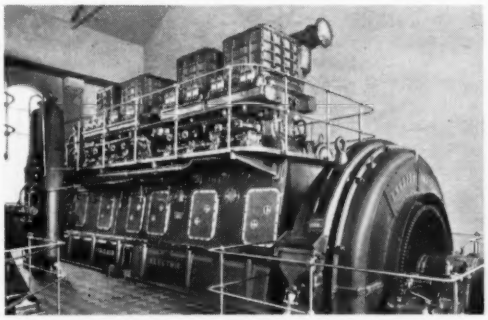

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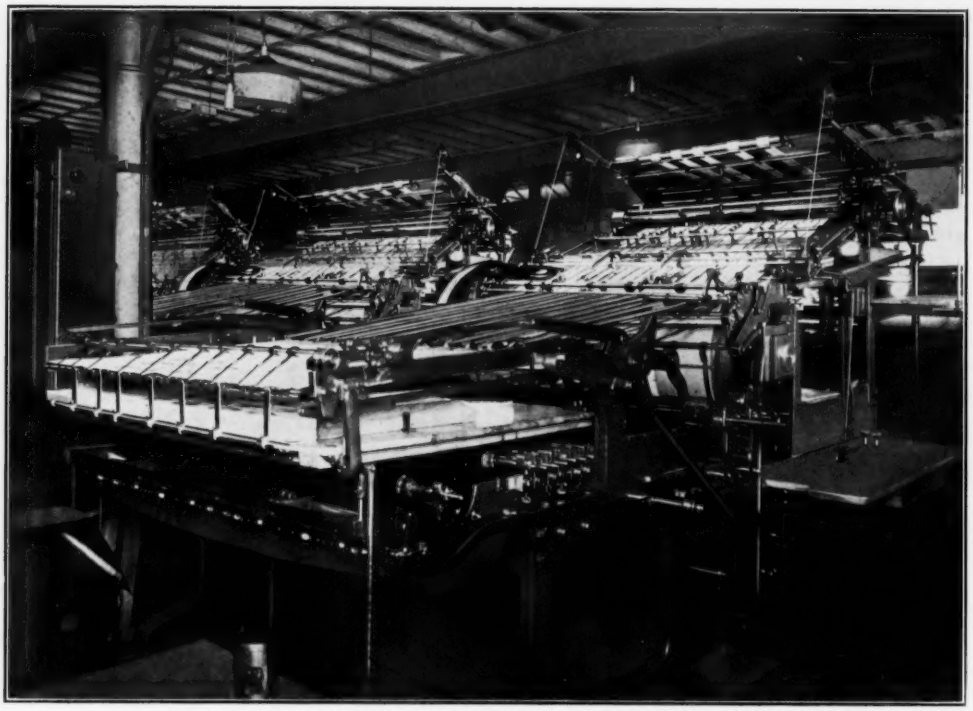

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